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Breton, Theodore R.



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Theodore R. Breton*

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Abstract

In 1960 Theodore Schultz expounded a human capital theory of economic growth that includes three elements: 1) Countries without much human capital cannot manage physical capital effectively, 2) Economic growth can only proceed if physical capital and human capital rise together, and 3) Human capital is the factor most likely to limit growth. I specify Schultz's theory mathematically and test it in periods when global financial capital was highly mobile. I find that in 1870, 1910, and 2000, the average schooling attainment of the adult population largely determined the stock of physical capital/capita and GDP/capita in 42 market economies.

JEL Codes: E13, I21, O11, O15, O41

Key Words: Human Capital, Schooling, Capital Investment, Economic Growth, Solow Model, Market Economies

*Universidad EAFIT, Carrera 49#7 Sur-50, avenida Las Vegas, Medellin, Colombia

ted.breton@gmail.com and tbreton@eafit.edu.co

574-250-5322 (home) 574-261-9334 (office) 574-261-9294 (fax)

I. Introduction

In the 1950s economists had little doubt that physical capital is the limiting factor in the growth of GDP/capita. But after observing the results from capital projects in countries at different levels of development, Theodore Schultz [1961] concluded that 1) countries without much human capital cannot manage physical capital effectively, 2) economic growth cannot proceed unless a country's human capital and physical capital rise together, and 3) since private investors are only interested in investing in physical capital, human capital is the factor most likely to limit growth.

Schultz's three conclusions can be viewed as elements of a complete human capital theory of economic growth. He expounded this theory in the Presidential address to the annual meeting of the American Economic Association in 1960.

Schultz did not formalize his theory by specifying a mathematical model, but the model is implied. The first element implies that the marginal product of physical capital (MPK) is a positive function of the level of human capital. If the level of human capital and physical capital are both low, the MPK will be low because the physical capital is not well-managed.

The second element implies that the MPK is subject to diminishing returns, so unless the level of human capital rises, increases in physical capital will reduce the MPK below the market return, which will prevent further investment in physical capital.

The third element implies that investment in physical capital is market-driven but investment in human capital is determined primarily by non-market forces. Due to the complementarity of the two kinds of capital, in a market economy the non-market forces end up determining whether human capital, physical capital, and economic output increase.

The first two elements of Schultz's theory are inherent characteristics of the Solow model when it is augmented with human capital. Since the marginal product of each type of capital is a function of the stock of the other type, either type of capital (or both) can be the factor limiting growth. The third element of Schultz's theory is also an inherent characteristic of the augmented Solow model if investment in physical capital is market-determined and investment in human capital is not [Breton, 2013b].

Given the considerable empirical evidence supporting the three elements of Schultz's theory, the main obstacle to its serious consideration appears to be the widespread acceptance of Hall and Jones' [1999] development accounting methodology, in which human capital is assumed not to have any external effects. Caselli [2005] presents this methodology as the accepted approach for estimating the effect of human capital. In this methodology a nation's level of schooling raises workers' productivity and income, but it does not have any external effects on economic output.

Breton [2013a] shows that Hall and Jones' methodology is invalid because a large external effect of human capital is mathematically implicit in their production function. With their assumption for the direct effect of schooling on workers' incomes, the external effect of schooling on national income is larger than its direct effect on workers' incomes.

If a multiplicative production function, such as the augmented Solow model, is a valid representation of a national economy, then the large external effects of human capital in this function have profound implications for growth. In this function if most families in poor countries are unwilling or unable to invest in their children's schooling and if charities or the state do not provide this schooling, then physical capital is not productive, and as Schultz concluded, the nation's low level of human capital limits investment in physical capital and the rate of growth.

In this paper I present a comprehensive evaluation of Schultz's theory. I begin by reviewing the Hall and Jones' development accounting methodology. I show that their assumption that human capital has no external effect is inconsistent with the structure of their production function and that the structure of the Mankiw, Romer, and Weil (MRW) model is more consistent with the historic cross-country evidence about the growth process. I then show that in a global financial capital market, with credit-constrained investment in human capital, the MRW model predicts that a nation's human capital/capita determines its physical capital/capita and its income/capita.

Subsequently, I perform two empirical tests of the model's prediction during historic periods when market economies were open to global flows of financial capital. In the first test I examine whether differences in physical capital/capita in market economies in 2000 are caused by national differences in average schooling attainment. In the second test I examine whether differences in GDP/capita (and implicitly physical capital/capita) in market economies are caused by national differences in average schooling attainment in 1870, 1910, and 2000. I instrument average schooling attainment in these tests to control for endogeneity.

I find that national differences in average schooling attainment explain 77% of the differences in physical capital/capita in 42 high and low-income countries in 2000 and that the quantitative relationship between physical capital and average schooling attainment is consistent with the relationship predicted by the MRW model. I also find that national differences in schooling attainment and exogenous world TFP growth explain 88% of the differences in GDP/capita in these high and low income countries over the 1870-2000 period. Again I find that the quantitative relationship between schooling attainment and GDP/capita is consistent with the relationship predicted by the MRW model. These results provide evidence that Schultz's theory of economic growth has merit.

This paper is organized as follows: Section II shows that the MRW model is consistent with the evidence relating education to growth in the literature and the Hall and Jones development accounting methodology is not. Section III derives the human capital growth model from the MRW model. Section IV describes the methodology for testing this model. Section V addresses the cross-country data measurement issues. Section VI presents the empirical results. Section VII concludes.

II. The MRW Model vs. the Hall and Jones Model

Hundreds of studies undertaken in countries at every stage of development have found that workers' salaries rise with increased schooling and with work experience [Psacharopoulos and Patrinos, 2004]. Other studies have shown that the increase in salary is related to improved worker productivity, as predicted in neoclassical theory [Krueger and Lindahl, 2001, and Hanushek and Woessmann, 2008]. These studies provide strong evidence that increases in a nation's level of schooling raise national income

The microeconomic studies of the effect of schooling do not identify the appropriate mathematical structure for a macroeconomic growth model. MRW [1992] argue that national income across countries can be represented by a Cobb-Douglas production function in which physical capital (K), human capital (H), labor (L), and total factor productivity (A) have a multiplicative effects on national income (Y):

$$1) \quad Y = K^{\alpha} H^{\beta} (AL)^{1-\alpha-\beta}$$

This model is similar to the Solow model in that it exhibits constant economies of scale and diminishing returns to investment in capital. Since $\alpha + \beta < 1$, investment in either physical capital or human capital, or in both are subject to diminishing returns. As a consequence, if $A_t = e^{gt}$ and a constant share of income is invested in each kind of capital, the model predicts convergence to a steady-state rate of growth g . MRW [1992] estimated this model in various ways

using cross-country data on secondary schooling enrollment rates and found that $\alpha \approx \beta \approx 0.3$.

Klenow and Rodriguez-Clare [1997] compared MRW's estimates of the effect of schooling on national income with its effect on workers' incomes in microeconomic studies and determined that MRW's estimate of $\beta \approx 0.3$ implies that the external effects of schooling on national income are considerably larger than the direct effect on workers' salaries. Since researchers had not found any indication that the external effects of schooling could be this large, Klenow and Rodriguez-Clare's analysis undermined confidence in the MRW model.

MRW's model has the confusing property that it provides workers with two streams of income, one related to their human capital and one related to their unskilled labor. Hall and Jones [1999] modified the MRW model to combine the human capital and labor factors into a variable hL with a single income stream:

$$2) \quad Y = K^\alpha (AhL)^{1-\alpha}$$

In this model all workers have the same level of human capital h , and they receive income based on their human-capital-augmented productivity. The structure of the Hall and Jones' model is easier to interpret than the MRW model, but its structure has problematic implications. Since $h = H/L$, Hall and Jones' model converts to:

$$3) \quad Y = K^\alpha (AH)^{1-\alpha}$$

This form of their model reveals that it has a constant return to total investment in physical and human capital, so it is implicitly an AK model, which does not converge to a steady-state rate of growth.

Caselli [2005] adopts Hall and Jones' [1999] model as the preferred methodology for development accounting because if α is the share of national income accruing to physical capital, then if human capital has no external effects, workers receive the remaining $1-\alpha$ share of income. But the assumption that

human capital has no external effects is inconsistent with the marginal product of physical capital in the model:

$$4) \quad MPK = \partial Y / \partial K = A^{1-\alpha} \alpha K^{\alpha-1} H^{1-\alpha}$$

In this model if $\alpha = 1/3$, as Hall and Jones assume, then $1-\alpha = 2/3$, which means that the external effect of human capital on MPK is implicitly very large.

The Hall and Jones model is not the only model in which human capital has an external effect. This effect is intrinsic in any production function that includes human capital as a multiplicative factor of production. In the MRW model in (1) human capital has two external effects, one on the marginal product of K and one on the marginal product of L [Breton, 2013a]:

$$5) \quad MPK = \partial Y / \partial K = A^{1-\alpha-\beta} \alpha (K/L)^{\alpha-1} (H/L)^{\beta}$$

$$6) \quad MPL = \partial Y / \partial L = A^{1-\alpha-\beta} (1-\alpha-\beta) (K/L)^{\alpha} (H/L)^{\beta}$$

A valid development accounting exercise using either the MRW model or the Hall and Jones model must account for the external effect(s) of schooling on the productivity of the other factor(s) of production.

There is empirical evidence that human capital affects the marginal products of physical capital and of (unschooled) labor, as predicted by the MRW model. Lopez-Bazo and Moreno [2008], Chi [2008], and Becker, Hornung, and Woessmann [2011] present evidence that the regional level of human capital/worker affected the regional level of physical capital/worker in Spain in 1980-2000, in China during 1996-2004, and in Prussia in the 19th century. Acemoglu and Angrist [2001], Moretti [2004], Liu [2007] and Fleisher, Li, and Zhao [2010] present evidence that educated workers have a positive spillover effect on the salaries (and implicitly the productivity) of other workers.

Breton [2013a] shows that once the two external effects of human capital in the MRW model are taken into account, a cross-country estimate of the effect of schooling on national income ($\beta = 0.36$) is consistent with the observed direct

effect of schooling on workers' incomes in 36 countries. In this estimate $\alpha + \beta = 0.7$, which supports MRW's [1992] finding that a nation's investment in capital is subject to diminishing returns.¹

Romer [2012] summarizes the empirical evidence rejecting the validity of the AK model. Historically growth rates have not increased with growth in physical and human capital, which indicates that total investment in capital is subject to diminishing returns. Historic evidence also supports the conditional convergence to a steady-state rate of growth in the MRW model, which requires the existence of diminishing returns. Another problem with the Hall and Jones model is that it assumes that $MPL = 0$, while the MRW model assumes that MPL is as function of capital/worker. As a consequence, the MRW model can explain the higher salaries for unskilled workers in more educated societies, but the Hall and Jones model cannot.²

This review indicates that the structure of the MRW model is consistent with the microeconomic evidence for the direct and the external effects of schooling on national income. This evidence does not indicate that human capital/worker entirely determines physical capital/worker nor that it is the principal factor limiting economic growth.³ But as shown in the next section, in a

¹ Breton [2013a] estimates human capital from expenditures on schooling and students' foregone earnings. There is controversy over whether 100% of expenditures on schooling are investment rather than consumption, but since Breton estimates the effect of human capital in log form, this estimate is unbiased as long as investment is the same share of expenditures across countries.

² An increase in unschooled workers raises national income more in a more educated society because when these workers substitute for more educated workers, they enable the highly educated workers to focus on tasks where they substantially raise the nation's marginal output.

³ Breton [2013a] shows that differences in physical and human capital explain 95 percent of income differences across 61 countries in 1990 and that the direct effect of other factors is small. commonly thought to affect income was small.

global financial capital market, the structure of the MRW model implies that this is the case.

II. Derivation of the Human Capital Growth Model

Since physical capital and human capital are complementary in the MRW model, each type of capital positively affects the marginal product of the other type:

$$7) \quad MPH = \partial Y / \partial H = A^{1-\alpha-\beta} \beta (K/L)^{\alpha} (H/L)^{\beta-1}$$

A quantitative relationship between K/L and H/L can be derived from the marginal product function in either (5) or (7).

From a mathematical standpoint the two types of capital are identical in the MRW model, but in actual financial markets they are not. In modern economies human capital is created primarily in schools, initially in primary and then in secondary schools. Since human capital cannot serve as collateral, private investment in elementary schooling has considerably greater financial risk than investment in physical capital. Mincer [1984] argued that in poor countries the high financing cost associated with this high financial risk precludes all but the rich from responding to the high return on investment in education. He also argued that investment in education becomes more market-determined as rising schooling levels raise average incomes and enable a larger share of the population to self-finance investment in schooling.

A number of recent studies present evidence that supports Mincer's arguments. Ben Mimoun [2008] shows that a country's level of financial market development affects secondary and tertiary schooling enrollment rates, which limits schooling to a greater degree in poor countries. Cordoba and Ripoll [2013] present cross-country evidence that credit frictions in capital markets limit schooling attainment. Breton [2013b] presents cross-country evidence that

investment in schooling was exogenous in 1910 but that it had become endogenous by 2000.

Easterlin [1981] and Soysal and Strang [1989] document that historically the creation and growth of schooling for the masses occurred chiefly in response to non-market forces, principally each nation's level of religious or state support for this schooling. Ben Mimoun [2008] and Cordoba and Ripoll [2013] show that a nation's level of schooling is affected by its support for public schooling. Schooling's dependence on non-market forces is the logical result of a severely credit-constrained market for private investment in schooling.

The restricted private financing for human capital in a market economy makes the stock of physical capital a function of the stock of human capital, rather than the reverse. Solving (7) for K/L yields:

$$8) \quad (K/L)_{it} = (\alpha/MPK_{it})^{1/1-\alpha} (A_t)^{(1-\alpha-\beta)/(1-\alpha)} (H/L_{it})^{\beta/1-\alpha}$$

Estimation of this model across countries requires data for the stock of physical capital and for the stock of human capital, most of which is created in schools.

The physical capital stock is typically estimated from historic rates of investment. Breton [2013a] uses the same approach to estimate human capital stocks from investment in schooling in 61 countries. He shows that the relationship in 1990 between these stocks and Cohen and Soto's [2007] estimates of average schooling attainment is log-linear and highly statistically-significant:

$$9) \quad \log(H/L) = a + 0.32 \text{ attainment}$$

Since average schooling attainment data are available from Morrison and Murtin [2009] for the period 1870-2000, and their data in 1990 are virtually identical to Cohen and Soto's [2007] data, the log-linear relationship in (9) is applicable to the current analysis.

In a global financial capital market, the return on investment in physical capital should tend to equalize across countries, eliminating national differences in the MPK. When economic functions are estimated from cross-country

economic data, the data must be adjusted to equalize purchasing power. This adjustment raises the relative price of physical capital in lower-income countries, so the adjusted MPK in these countries is higher [Caselli and Feyrer, 2007]. If financial returns rk_t are the same across countries, a nation's adjusted MPK is a function of the adjusted domestic price of physical capital pk_{it} , the global return on financial capital and the depreciation rate.⁴ If the annual depreciation rate for physical capital is 6 percent [Caselli, 2005], this MPK is approximately:

$$10) \quad MPK_{it} \approx c \, pk_{it}^{1.65} \, rk_t$$

Adopting the standard Solow assumption that $A_t = A_0 e^{gt}$, assuming that rk_t is constant over time, and employing the relationships in (9) and (10), in a global financial capital market, the physical capital model in (8) can be converted to a linear model of physical capital/worker:

$$11) \quad \log(K/L)_{it} = c + (-1.65/(1-\alpha)) \log(pk_{it}) + 0.32 \beta/(1-\alpha) \text{Schooling}_{it} + (1-\alpha-\beta)g/(1-\alpha) t + \varepsilon_{it}$$

Since this model is derived from the augmented Solow model, the implied value of α should be consistent with its predicted value in the Solow model, which is equal to physical capital's share of national income. Bernanke and Gurkaynak [2001] present evidence that this value is approximately 0.35 across countries.

The model in (11) can be simplified further because the adjusted domestic price of physical capital pk_{it} is implicitly a function of the nation's level of human capital. The logic for this is as follows. Hsieh and Klenow [2007] document that the (unadjusted) prices of capital goods are similar in low and high income countries, but the (unadjusted) prices of consumer goods are lower in low-income countries. They conclude that the prices of consumer goods are lower because

⁴ Home bias in investment and country-specific differences affecting investment risk create country-specific differences in MPK [Coeurdacier and Rey [2013], but in this analysis I assume these differences are random.

low-income countries have lower productivity in the production of investment goods or in the production of tradable goods to exchange for imported investment goods.

As shown in (6) the augmented Solow model attributes the lower productivity in the production of tradable goods in low-income countries to the smaller external effects of human capital and physical capital on the productivity of (unschooled) labor in these countries:⁵ Since the augmented Solow model predicts that in a global financial capital market, physical capital/worker across countries is the same if human capital/worker is the same, implicitly the adjusted domestic price of physical capital is entirely a function of the nation's level of human capital:

$$(12) \quad Pk_{it} = c (H/L)_{it}^{-\theta}, \text{ where } \theta > 0$$

This relationship can be used to convert (11) into a model in which physical capital/worker is entirely a function of a nation's average level of schooling:

$$(13) \quad \log(K/L)_{it} = c + 0.32 (1.65 \theta + \beta)/(1-\alpha) \text{ Schooling}_{it} + (1-\alpha-\beta)g/(1-\alpha) t + \varepsilon_{it}$$

If data on the physical capital stock are not available in some years, the hypothesis that human capital determines physical capital can be tested by examining whether the relationship between GDP/worker and average schooling attainment is consistent between these years and other years in which data for physical capital are available. Mathematically, the relationships in (1), (9), and (13) imply that in a global market for financial capital, GDP/worker at any time t is entirely a function of average schooling attainment:

$$(14) \quad \log(Y/L)_{it} = c + 0.32(1.65 \alpha \theta + \beta)/(1-\alpha) \text{ Schooling}_{it} + (1-\alpha-\beta)g/(1-\alpha) t + \varepsilon_{it}$$

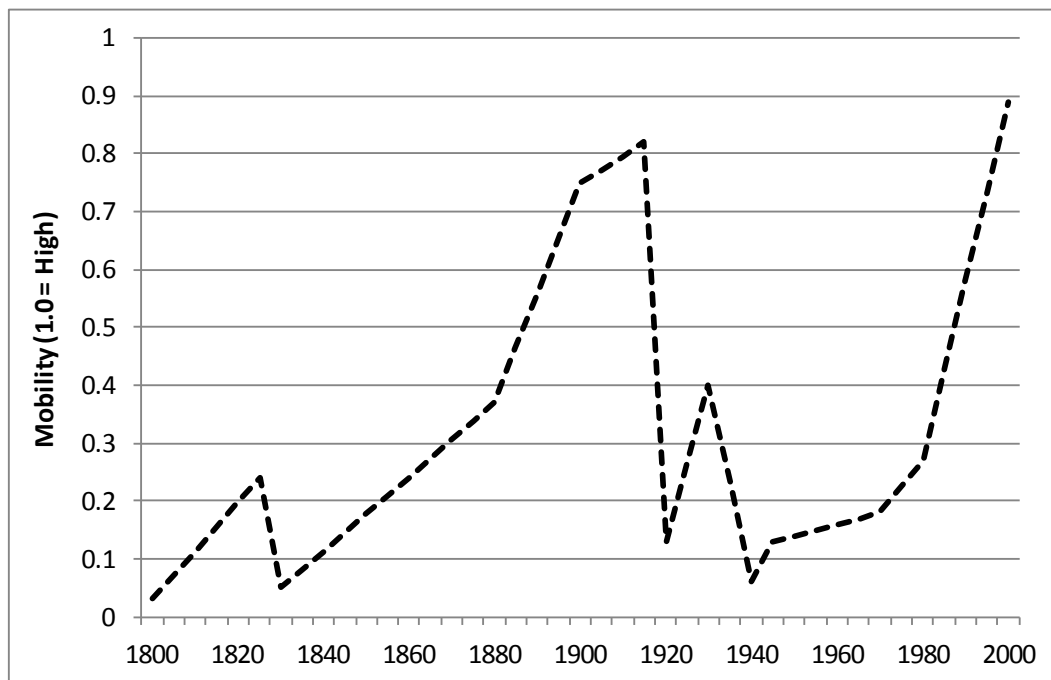
The models in (13) and (14) can be estimated using cross-country data in years that follow periods of high mobility in the global financial capital market.

III. Model Estimation

⁵ See Breton [2013a] for a more extensive treatment of the inherent external effects of human capital on physical capital and (unschooled) labor in the augmented Solow model.

Obstfeld and Taylor [2004] have created an index of global financial capital mobility for the period 1800 to 2000, which identifies the periods when global financial capital was most influential in domestic investment decisions. This index is shown in Figure 1. According to this index, the historic periods with the highest global capital mobility between 1800 and 2000 were the 25 years from 1890 to 1915 and the ten years from 1990 to 2000.

Figure 1
Mobility of Global Financial Capital: 1800-2000



Caselli and Feyrer [2007] estimate the marginal product of reproducible physical capital across countries in 1996, a year of high global capital mobility, and find it was very similar in both high and low income countries. In fact, their analysis shows that the MPKs for reproducible capital were lower in the lowest-income countries. They conclude that domestic financial capital constraints did

not limit investment in lower-income countries in 1996. Their analysis supports the assumption that in 2000 physical capital/worker in market economies was determined primarily in the global financial capital market.

Obstfeld and Taylor argue that in 1910 global financial capital was at least as available in poor countries as in 2000 because the pre-1914 period was characterized by *laissez-faire* national economic policies with respect to global labor and capital flows and most countries had adopted the gold standard. They present data showing that spreads on long-term government bonds were particularly low in poor countries between 1905 and 1914 (0.5 to 3.0 percent), that 70 percent of all financial capital flowed to the private sector, and that levels of private foreign investment were quite high in many poor countries. Their information strongly supports the assumption that in 1910 physical capital/worker was determined primarily in the global financial capital market.

Obstfeld and Taylor's index indicates that global mobility was lower in 1870 than during the 1890-1915 period, but higher than during the 1940-1980 period. Arrighi [2010] reports that British exports of railroad iron and steel and machinery increased substantially between 1850 and 1870, flowing to Central and South America, the Middle East, Asia, and Australasia. He also presents data showing that exports of British financial capital surged after 1855. This information indicates that by 1870 physical capital/worker in market economies already was determined, or at least heavily affected, by the global financial capital market.

Morrison and Murtin [2009] have created data on average schooling attainment for 74 countries for each ten-year period between 1870 and 2010. Maddison [2003] has created data for GDP/capita for a large number of countries for many years during the period from 1910 to 2000 and for a smaller number of countries back to 1870. The information on global financial capital mobility and

the availability of schooling and economic data for 1870, 1910, and 2000 make these years suitable for testing Schultz's growth theory.

Since investment in schooling is likely to be more market-driven in countries with higher levels of income, average schooling attainment is likely to be endogenous in the estimated models. A country's level of Protestant affiliation can be used as an instrument for schooling because it has been correlated with literacy and schooling across regions and countries for centuries [Means, 1966, Cipolla, 1969, Johansson, 1981, Soysal and Strang, 1989, Goldin and Katz, 1998, and Becker and Woessmann, 2010]. The correlation has a firm conceptual basis, since the founders of several Protestant sects (e.g., Luther and Calvin) emphasized the importance of literacy so that their members could read the Bible. In addition, the Catholic Church issued encyclicals forbidding their members' attendance in secular schools [Johnson, 1976], which is likely to have restricted Catholics' schooling attainment. Even in largely non-Christian countries, low levels of Protestant affiliation are associated with higher levels of schooling because Protestant missionaries created elementary schools [Ferguson, 2011].

Protestant affiliation is not a perfect instrument because it could affect GDP/capita directly. Weber [2000 (1905)] argued that the Protestants have a greater work ethic and are likely to consume less than Catholics, but his hypotheses have been tested and consistently rejected. Iannaccone [1998] summarizes many of these findings. Becker and Woessmann [2009] show that in 453 counties in Prussia in 1871, incomes were higher in Protestant than in Catholic counties, but that after controlling for the effect of literacy, the difference in economic success is not significant. Using data from 32 countries, Arruñada [2010] rejects the hypothesis that Protestants have a greater work ethic than Catholics, although he does find evidence that Catholics have a different social ethic, preferring to work in family-related businesses and relying more on family connections than Protestants. Breton [2004] presents cross-country evidence

showing that Protestant affiliation is not correlated with the quality of institutions. In all of these studies and tests, there is no evidence that Protestant affiliation affects national income other than through its effect on the level of schooling.

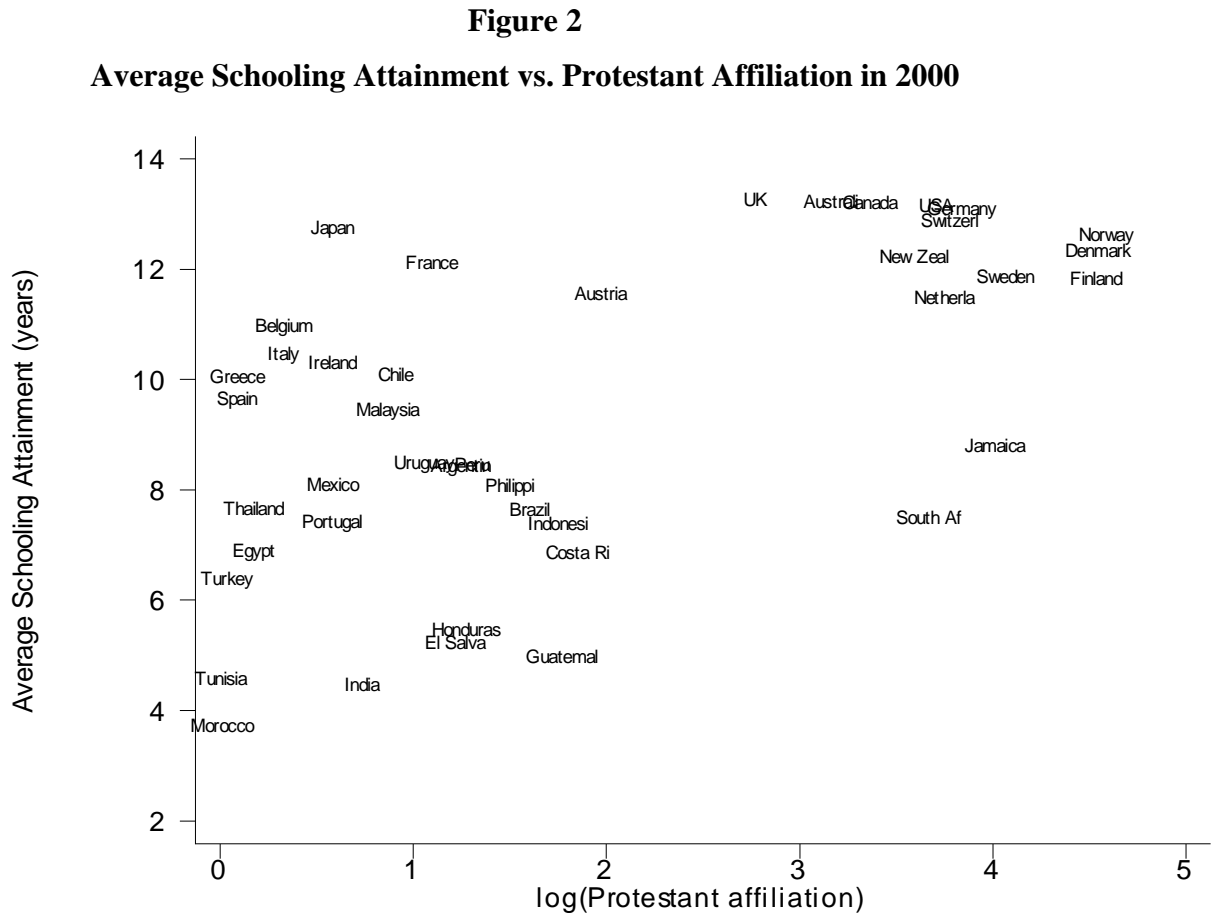
Barrett [1982] provides data on religious affiliation for countries worldwide for 1900 and 1980, which makes the instrument most appropriate for analyses of schooling in 1910 and 2000. But relying on the stability of religious affiliation rates during the late 19th century, I also use the 1990 affiliation data as an instrument for schooling in 1870. The instrument is the log of the share of “professing Protestants,” measured in percentage terms +1, so that countries with no affiliation have an instrument with a value of 0. The relationship between these data and average schooling attainment in 2000 is shown in Figure 2. The correlation coefficient for these data is 0.58, and the relationship is similar in 1900.

Given the limitations of the data, I test Schultz’s hypothesis in two ways: First, by estimating the cross-sectional relationship between physical capital/capita and average schooling in 2000 and then by estimating the cross-sectional and time series relationships between GDP/capita and average schooling levels in 1870, 1910, and 2000. This time period includes the most dynamic period in the history of capitalism and almost all of the period during which any countries had substantial levels of schooling. If the empirical results from these analyses are statistically-significant and consistent in these two tests and are stable over this 130-year period, they provide evidence that Schultz’s theory of economic growth has merit.

IV. Data Reliability and Sources

Recently researchers have questioned whether the cross-country economic and schooling data are sufficiently reliable for use in econometric estimation. The problem with the economic data is that the normal measurement error inherent in these data is exacerbated when these data are adjusted for differences in

purchasing power across countries. The problem with the schooling attainment data (years of schooling) is that they are at best a rough measure of human capital, and Hanushek and Woessmann [2008 and 2012] argue that they are a particularly poor measure across countries because schooling quality varies so much.



All of the cross-country economic data sets are based on National Accounts data, but different data sets include different adjustments for purchasing power. These adjustments are problematic because they require prices for the same goods and services, and these prices are only available historically for a

subset of less-developed countries and for different years for different countries. In addition, these prices often do not account for differences in the quality of products, and particularly of services, and in some countries the surveyed prices are only representative of urban areas [Deaton and Heston, 2010].

Johnson, Larson, Papageorgiou, and Arvind [2013] show that the economic data are not consistent even within different versions of Penn World Table 6, which are based on the same price surveys. Breton [2012] shows that the differences in the economic data are even larger between versions of Penn World Table 6 and 7, which are based on different price surveys. However, Johnson, et. al. [2013] also show that while growth analyses are not robust across different versions of PWT 6 using annual income data, they are robust over periods longer than 10 years because growth rates in the PWT 6 data sets reflect the growth rates in the underlying National Accounts data. Breton [2012] presents evidence that the PWT 6.3 data are more reliable than the PWT 7.0 data, since PWT 6.3 makes use of all the historic price surveys, while PWT 7.0 uses only the ICP 2005 prices.

In this study I minimize bias due to measurement error in the economic data by estimating relationships across countries and over time periods that span at least 40 years. I also use an instrument for schooling which avoids the attenuation bias associated with OLS estimates.

I use economic data from Maddison [2003] and from PWT 6.3 [Heston, Summers, and Aten, 2009]. Maddison's data do not include investment rates and prices for investment and GDP, so I obtain these rates and prices from PWT 6.3. I use the PWT 6.3 data to augment the Maddison data because both data sets make use of the same international benchmarked prices in 1993 and 1996 to adjust National Accounts data. As a consequence, they have similar estimates of GDP/capita in 2000, and the relationship in 2000 between GDP/capita and the physical capital stock in PWT 6.3 is a reasonable proxy for the relationship between these variables in the Maddison data in that year.

There is also considerable debate in the literature about the accuracy of different measures of human capital [Hanushek and Woessmann, 2008, 2012a, and 2012b and Breton, 2011]. Most cross-country analyses utilize measures of a nation's average schooling attainment to represent human capital. Early versions of the Barro and Lee [2001] schooling attainment data exhibit considerable measurement error, which led to substantial attenuation bias in OLS estimates of the effect of schooling [Krueger and Lindahl, 2001].

Cohen and Soto [2007] revised the Barro and Lee data and then obtained reasonable estimates of the effect of schooling on national income across countries over the 1960-90 period. Morrison and Murtin [2009] have refined Cohen and Soto's average schooling data further and extended them back to 1870. These data appear to have considerably less measurement error than the original Barro and Lee data.

Hanushek and Woessmann [2008, 2012a, and 2012b] criticize the schooling attainment data on different grounds. They argue that average schooling attainment is a poor measure of human capital because it does not account for differences in schooling quality across countries. They claim that the schooling attainment data assume that a year of schooling provides the same amount of education across countries.

Hanushek and Woessmann's characterization of the average schooling attainment measure is incorrect. While the measure does not explicitly take schooling quality into account, it does not assume that each year of schooling provides the same amount of education. What the measure assumes is that countries with the same average years of schooling (e.g., the U.S. and Canada) have the same level of human capital, irrespective of whether this capital was created in schools or elsewhere. The best way to think about the measure is that it assumes that a country's average level of schooling is a proxy for its level of human capital.

The amount of education provided in each additional year of average schooling attainment is not specified, and it depends on the mathematical form used to relate GDP/capita to average schooling attainment in the income model. Most national income or growth models (including the models in this study) employ the Mincerian log-linear relationship between national income and average schooling attainment. In these models the implicit assumption is that the stock of human capital increases *exponentially* as the average level of schooling rises.

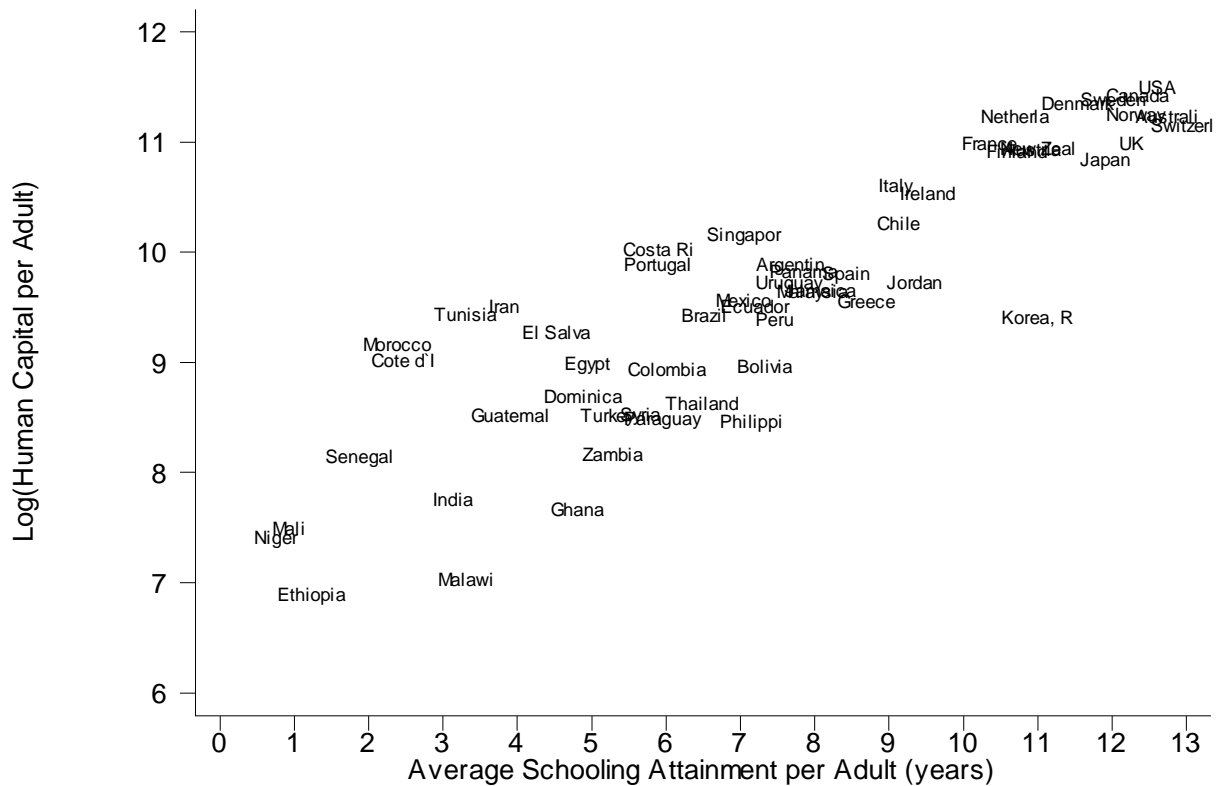
The estimated coefficient on the schooling variable measures the effect of greater average schooling attainment on national income. If there is a tendency for schooling quality, or any aspect of a nation's human capital, to increase as average schooling attainment rises, then this tendency is captured in the estimated coefficient on the effect of schooling. Since average scores on tests of student skills tend to be higher in countries with higher average schooling levels [Breton, 2011], the tendency for school quality to increase with greater average attainment is implicitly taken into account in the estimate of the effect of average schooling attainment on national income.

Breton [2013a] shows that a nation's average schooling attainment is highly correlated with $\log(H/L)$, where H/L is the financial stock of human capital/adult estimated from cumulative investment in schooling. This relationship is shown in Figure 3. Since Lee and Barro [2001] found that a country's schooling quality is related to its cumulative investment in schooling, the average schooling attainment measure implicitly accounts for the higher average quality of schooling at higher levels of average attainment.

As shown in Cohen and Soto [2007] and Breton [2013], regressions of national income on average schooling attainment countries that utilize a log-linear relationship produce estimates of the effect of schooling that are large and statistically robust across countries or over 30-year periods. The failure to find

effects of changes in schooling over short periods is due in part to measurement error, but also to short-term economic fluctuations and to the varying lags between students' completion of schooling and the onset of employment. These short-term measurement problems diminish in importance when the effect of schooling on national income is examined over longer periods.

Figure 3
Log(Human Capital/Adult) vs. Average Schooling Attainment in 1990



In this study I use data for 42 countries that were market economies between 1870 and 2000 and that have consistent GDP/capita data in the PWT 6.3

and Maddison [2003] data sets.⁶ I exclude the Central European and Asian countries that had planned economies until 1990, since these economies are unlikely to have had economic relationships in 2000 that are entirely market-determined. I use Maddison's GDP/capita data for 1913 for a few countries that do not have data for 1910. In 1870 I use data for only 36 countries because Maddison's economic data are not available for six Latin American countries prior to 1910. I use Morrison and Murtin's [2009] data on the average schooling attainment of the population age 15 to 64 in 1870, 1910, and 2000.

I use the PWT 6.3 data series for the current investment rate (ci) and GDP/capita ($rgdpch$) for 1960-1999, and I assume an annual depreciation rate of 0.06 to estimate the physical capital stock for in 2000. I use the average of the PWT 6.3 prices for investment and GDP (pi/p) for the period 1995-99 to represent the domestic price of physical capital in 2000. I estimate all the models using per capita data. I use Barrett's [1982] data on Protestant affiliation in 1900 and 1980.

V. Empirical Results

Table 1 presents the empirical results for the analysis of whether the physical capital stock/capita across countries was determined by a nation's average schooling attainment in 2000. These analyses all utilize economic data obtained from PWT 6.3.

The first three columns examine whether the data for the 42 countries provide acceptable estimated coefficients for the augmented Solow model. The OLS and the 2SLS results are acceptable, but the 2SLS estimates are superior. The Hausman test in column 3 rejects the hypothesis that average schooling attainment is endogenous in 2000, but the implied value of α (0.25) in the OLS estimate is low. In the 2SLS results the implied value of α (0.36) is more consistent with expectations, and the implied value of β (0.37) is reasonable.

⁶ I excluded Syria from the data set because the GDP/capita data were very different in the PWT 6.3 and Maddison data sets.

These 2SLS estimates are very similar to Breton's [2013] estimates of the coefficients for the augmented Solow model in 1990, using human capital data estimated from investment in schooling.

Table 1 Effect of Average Schooling Attainment on GDP/capita and K/capita in 2000 [Dependent Variable is Log(GDP/Capita or K/Capita)]									
	1	2	3	4	5	6	7	8	9
Technique	OLS	2SLS	OLS	OLS	2SLS	OLS	OLS	2SLS	OLS
Countries	42	42	42	42	42	42	42	42	42
Dep. Var.	GDP/c	GDP/c	GDP/c	K/cap	K/cap	K/cap	K/cap	K/cap	K/cap
Log(K/Y)	0.34 (.22)	0.57 (.27)	0.57 (.27)						
Attainment	0.23* (.03)	0.19* (.04)	0.25* (.03)	0.21* (.03)	0.15* (.04)	0.23* (.03)	0.33* (.03)	0.27* (.05)	0.36* (.03)
Log(pi/p)				-1.72* (.31)	-2.15* (.37)	-2.15* (.37)			
Estimated Attainment			-0.07 (.05)			-0.09 (.04)			-0.09 (.05)
R ²	.81	.79	.81	.88	.86	.89	.77	.74	.78
Implied α	.25	.36		.04	.23				
Implied β	.54	.37		.63	.36				
Note: Robust standard errors in parentheses *Significant at one percent level									

Columns 4-6 present a similar set of estimates for the model of physical capital/capita (K/L) in 2000 that includes the domestic price of physical capital. The implied value of α (.04) in the OLS estimate is unacceptable, and the Hausman test in column 6 shows clearly that average schooling attainment is endogenous in this model. The 2SLS results are far superior, with acceptable implied values of $\alpha = 0.23$ and $\beta = 0.36$. The estimated effect of average schooling attainment on physical capital/capita in these results is statistically significant at the one percent level. The estimate of the implied value of α is low,

but surprisingly reasonable, given that it is estimated from cross-country prices for investment, including relatively inaccurate prices for investment in construction. The 2SLS estimate of the model explains 86 percent of the variation in physical capital/capita. These results provide evidence supporting the validity of the augmented Solow model.

Columns 7-9 shows a similar set of estimates for the model in which physical capital/capita (K/L) model is solely a function of average schooling attainment. The Hausman test in column 9 does not formally reject the hypothesis that schooling is endogenous, but the superiority of the 2SLS results in columns 4-6 indicates that the 2SLS estimates of the simple model in column 8 are also likely to be less biased than the OLS results in column 7.

In the 2SLS estimates of this model, the effect of average schooling attainment is statistically significant at the 1 percent level, and the model explains 74 percent of the variation in physical capital stock/capita. This result provides considerable evidence that in a global financial capital market, the level of human capital in a market economy (largely) determines the physical capital stock. The use of an instrument in the analysis indicates that the relationship is causal. Figure 4 shows the relationship between these physical capital/capita and average schooling attainment in the 42 countries in 2000.

Figure 4
Physical Capital/Capita and Average Schooling Attainment in 2000

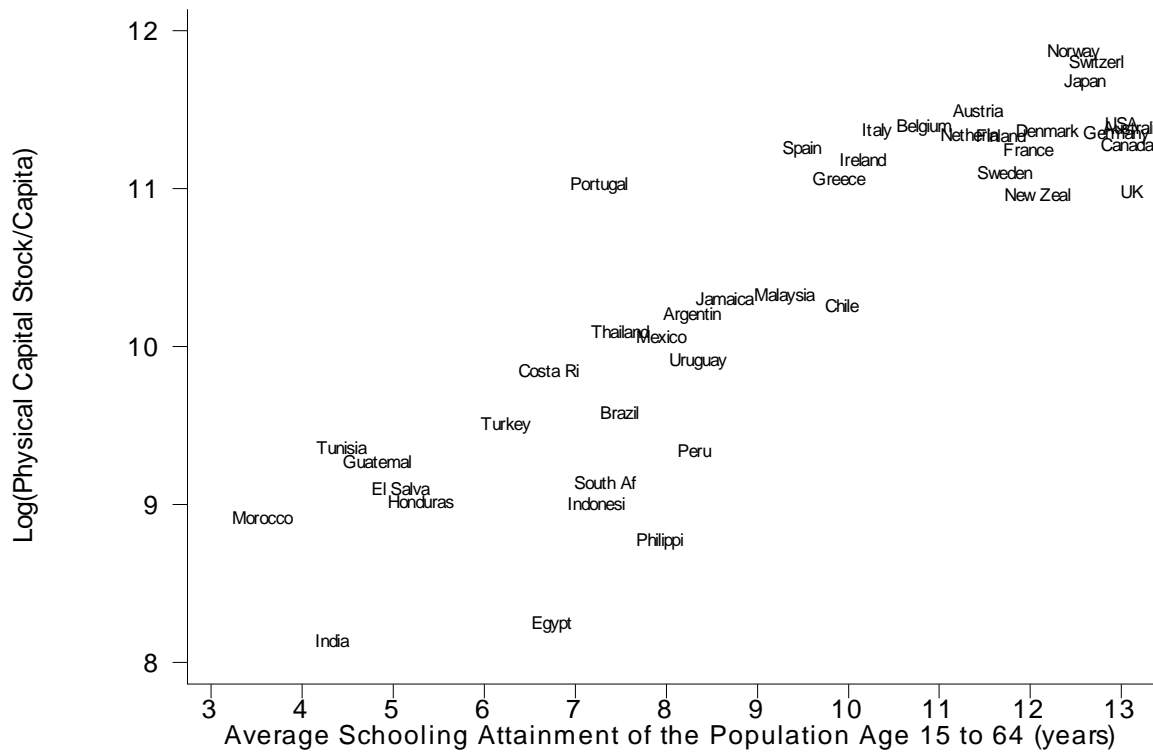


Table 2 shows the effect of average schooling attainment on GDP/capita in 2000 using data from both PWT 6.3 and Maddison [2003] to ensure that the estimated relationships are similar in the two data sets. Columns 1 to 3 present estimates for OLS, 2SLS, and a Hausman test for the standard augmented Solow model using PWT 6.3 data. Although the Hausman test does not formally reject the hypothesis that average schooling attainment is endogenous, again the 2SLS estimate provides more acceptable implied values of α and β than the OLS estimate.

Table 2 PWT 6.3 vs. Maddison: Effect of Average Schooling Attainment in 2000 [Dependent Variable is Log(GDP/Capita)]									
	1	2	3	4	5	6	7	8	9
Technique	OLS	2SLS	OLS	OLS	2SLS	OLS	OLS	2SLS	OLS
Countries	42	42	42	42	42	42	42	42	42
Data Source	PWT 6.3						Maddison		
Log(K/Y)	0.34 (.22)	0.57 (.27)	0.57 (.27)						
Attainment	0.23* (.03)	0.19* (.04)	0.25* (.03)	0.26* (.02)	0.22* (.03)	0.28* (.02)	0.27* (.02)	0.21* (.04)	0.30* (.02)
Estimated Attainment			-0.07 (.05)			-0.06 (.03)			-0.10 (.04).
R ²	.81	.79	.81	.79	.77	.80	.80	.75	.82
Implied α	.25	.36							
Implied β	.31	.30							
Note: Robust standard errors in parentheses *Significant at one percent level									

The results in columns 4 to 6 show that in models using PWT 6.3 data, average schooling attainment alone can explain the variation in GDP/capita almost as well as average schooling attainment and physical capital together. In the 2SLS estimates the complex model explains 79 percent of the variation, while the simple model explains 77 percent. This similarity is more evidence that the stock of physical capital/capita is determined by the average level of schooling attainment.

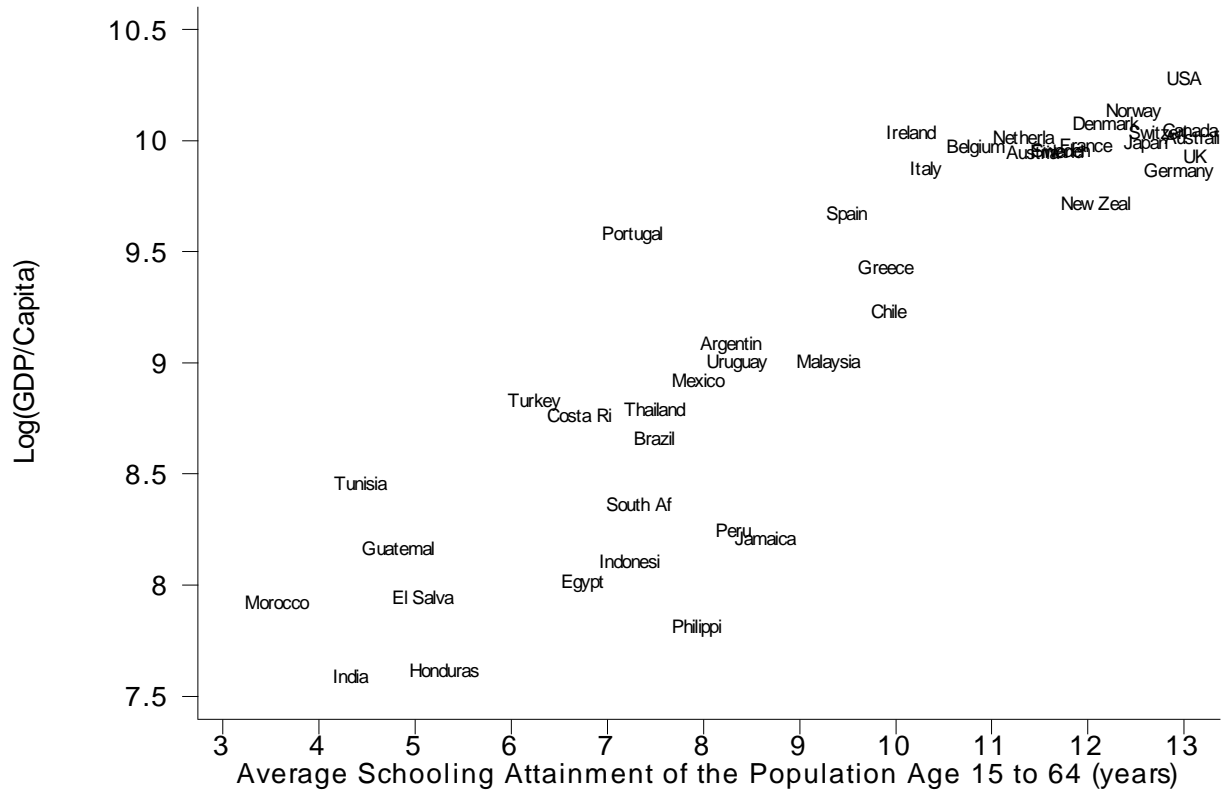
The similarity of the estimated coefficients on average schooling attainment in columns 4-6 and 7-9 indicate that the GDP/capita data in PWT 6.3 and Maddison are similar. In these estimates the Hausman test provides clear evidence that average schooling attainment is endogenous, indicating that the OLS estimates of the effects of schooling are biased upward.

In their recent analysis of the determinants of development in 1569 sub-national regions worldwide, Gennaioli, La Porta, Lopez-de-Silanes, and Shleifer [2013] find that a year of average schooling attainment in 2005 is associated with a 26 percent increase in GDP/capita. Their estimate is similar to the OLS estimates of 26 and 27 percent in Table 2, with the two data sets used in this study. In the 2SLS estimates in Table 2, each incremental year of schooling raises GDP/capita by 22 percent in the PWT 6.3 data and by 21 percent in the Maddison data. These results provide evidence that the OLS estimates in Gennaioli, et.al. are biased upward.

Figure 5 shows the relationship between GDP/capita in Maddison [2003] and average schooling attainment in 2000. The correlation is higher than in the relationship between physical capital/capita and average schooling attainment in PWT 6.3 data set, but this result is not surprising, since the estimates of physical capital/capita are based on the estimated price of investment, including the price of construction, which is difficult to measure consistently across countries.

Table 3 presents the estimates of the relationship between average schooling attainment and GDP/capita over the 1870 to 2000 period. All of the estimates use Maddison's GDP/capita data. Columns 1-6 present the cross-sectional results in 1870, 1910, and 2000, estimated using OLS and 2SLS with the Protestant share instrument. The consistency of the OLS and 2SLS estimates in 1870 and 1910 indicates that average schooling attainment was exogenous in those years when GDP/capita was low across countries. The evident endogeneity bias in the OLS estimates in 2000 supports Mincer's [1984] contention that investment in schooling becomes more market-driven as rising personal incomes facilitate the self-financing of education.

Figure 5
GDP/Capita in Maddison [2003] and Average Schooling Attainment in 2000



The 2SLS estimates of the effect of average schooling attainment are virtually identical in 1870, 1910, and 2000. An additional year of average schooling attainment consistently raises GDP/capita by 21 percent. This analysis indicates that increases in average schooling attainment have caused GDP/capita in a consistent manner for 130 years.

Table 3 Effect of Average Schooling Attainment on GDP/capita in 1870, 1910 and 2000 [Dependent Variable is Log(GDP/Capita)]										
	1870		1910		2000		1870-2000			
	1	2	3	4	5	6	7	8	9	10
Sample Size	36	36	42	42	42	42	120	120	120	120
Countries	36	36	42	42	42	42	42	42	42	42
Technique	OLS	2SLS	OLS	2SLS	OLS	2SLS	OLS	2SLS	FE	OLS
Attainment	0.21* (.03)	0.22* (.05)	0.21* (.01)	0.21* (.03)	0.27* (.02)	0.21* (.04)	0.23* (.01)	0.21* (.02)	0.14* (.02)	0.25* (.02)
Estimated Attainment										-0.03 (.03)
Year							.004* (.001)	.004* (.001)	.009* (.001)	.002 (.001)
R ²	.57	.57	.71	.71	.80	.75	.88	.88		.89
Implied g								.010		
ΔTFP/year								.003		
Note: Robust standard errors in parentheses *Significant at one percent level										

Columns 7-10 present the results for the 1870-2000 period using the same data. Since the relationship between average schooling and GDP/capita is stable over time, and the time trend is statistically significant, there is clear evidence of a steady rate of TFP growth over the 1870-2000 period. In the 2SLS estimates in column 8, the coefficient on time is $(1-\alpha-\beta)g/(1-\alpha) = .0042$. Using the estimates of $\alpha + \beta = 0.73$ from Table 1, the steady-state rate g is 1.0 %/year, and the TFP growth rate is $0.27 \times .0010 = 0.3\%/year$.⁷ Although not shown, these values are the same for the shorter 1910-2000 period. The variation in schooling and the TFP

⁷ The statistical results for the first stage of this estimate provide assurance that Protestant affiliation is a valid instrument for schooling:

$$(8) \quad \text{Attainment} = 0.95 \log(\text{ProtShare}) + 0.054 \text{ year} - 100.1 \quad R^2 = .76$$

(.10) (.003) (6.2)

trend explain 88 percent of the variation in GDP/capita over the 130-year period, with schooling explaining the larger share of the variation.

Column 9 presents an OLS estimate of the effect of schooling attainment on GDP/capita that controls for country-specific fixed effects. As is normal, the estimated coefficient on schooling is smaller (0.14 vs. 0.21) than in the 2SLS results. These results provide assurance that the large estimated effect of schooling is not due to country-specific omitted variables. The larger 2SLS estimate of schooling's effect is likely to be more accurate because measurement error causes attenuation bias in OLS estimates.

Figure 6 shows the 2SLS relationship between $\ln(\text{GDP/capita})$ and schooling in the three estimated years. The difference between GDP/capita in the fitted function and in the data in 2000 is due to the reverse causality from GDP/capita to schooling in countries with higher levels of GDP/capita.

VI. Conclusions

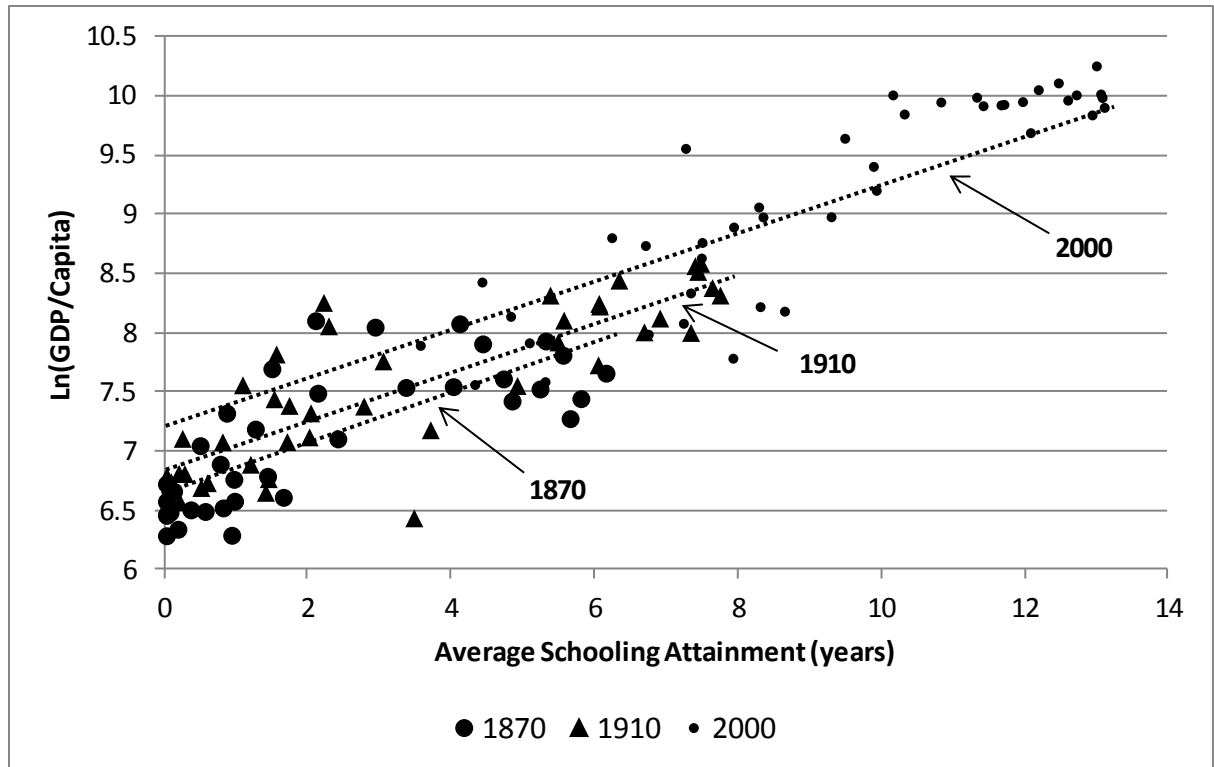
Although economists have traditionally assigned physical capital the central role in economic growth, Schultz [1961] argued that economic growth cannot proceed unless a nation's human capital and physical capital rise together. He further argued that since private investors are only interested in investing in physical capital, human capital is the factor most likely to limit a nation's economic growth.

In periods of high financial capital mobility, investment in physical capital in market economies is likely to be determined in the global capital market. Under these conditions, if human capital/worker is determined by non-market forces, the augmented Solow model predicts that in market economies it will determine physical capital/worker and GDP/worker. Taking advantage of the high mobility of global financial capital in the years prior to 1870, 1910, and 2000, I estimate a series of econometric models to determine whether average

schooling attainment determined physical capital/capita and GDP/capita in 42 countries.

Figure 6

2SLS Estimates of GDP/capita vs. Average Schooling Attainment



In the results for 2000, I find that 77 percent of the variation in physical capital/capita in 42 market economies is explained by differences in the average schooling attainment of the population age 15 to 64. In the results for 1870-2000, I find that 88 percent of the variation in GDP/capita in these same economies is explained by the differences in average schooling attainment and the trend in TFP growth. As both of these results are 2SLS estimates, they indicate that the differences in average schooling attainment caused the differences in physical

capital/capita and GDP/capita. These results provide evidence that Schultz's human capital theory of economic growth has merit.

These results and those from an increasing number of other studies indicate that physical capital is not the fundamental factor that determines economic growth. Physical capital and human capital appear to be equally important in raising economic output, but since investment in physical capital is market-determined in market economies and investment in human capital generally is not, the evidence indicates that country-specific forces determining a nation's investment in schooling largely determine the growth of physical capital and the growth of output in these economies.

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